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Monterey, California

IMPROVED SWEEP WAVEFORM GENERATOR
FOR BISTATIC RADAR

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IMPROVED SWEEP WAVEFORM GENERATOR FOR BISTATIC RADAR

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ABSTRACT

Although bistatic radar gives poorer range performance and poorer resolution than monostatic radar, bistatic radars have important uses. Improved circuits are described for generating the nonlinear waveforms required to give undistorted display in a bistatic radar.

INTRODUCTION

Monostatic pulse radars generally employ a single high-gain antenna for transmitting and receiving. In bistatic radars, on the other hand, transmitting and receiving installations may be separated by several miles. Since a high-gain receiving antenna could not look along the same path as the distant transmitting antenna, a low-gain, essentially omnidirectional receiving antenna is generally used. Reducing the gain of the receiving antenna by say 30 dB reduces the radar range by a factor of about 5.6. Cross-range resolution is also lost in a bistatic radar since one-way antenna beam width is greater than two-way beam width. Why, then, employ bistatic radar? There are at least two important applications for military bistatic radar: the location of enemy emitters, and surveillance when the tactical situation does not permit the activation of a radar transmitter.

On land camouflage can make very difficult the visual spotting of an enemy radar installation. If homing on the signal is attempted, the radar may very well be shut down. Bistatic radar may make it possible to pinpoint the emitter passively without approaching close to it. If a search radar

illuminates prominent radar targets such as bridges and mountains, timing of the echos of these objects relative to the direct signal from the radar to a bistatic receiver can supply all the information necessary to locate the radar.

In many situations radar transmitters and other emitters cannot be turned on because to do so would give away the location of a high-value target such as an aircraft carrier. Emissions from a radar can be detected at a range much, much greater than the maximum target detection range of the radar. Bistatic radar can provide the means for surveillance when the monostatic radar transmitter cannot be turned on. The bistatic transmitter can be a cooperative transmitter on another ship or on an aircraft, or it may be a noncooperative enemy radar transmitter. To obtain data to generate the radar display at a bistatic receiver it is necessary to know the direction and distance to the transmitter. The direction may be obtained by direction-finding techniques. The distance may be estimated, may be determined from intelligence information, or may be determined by a passive technique such as maneuver ranging.

DISPLAY DISTORTION

In monostatic radar the incident signal and the echo traverse the same paths, but in opposite directions. The total signal path length is then 2R, and the total signal transit time, which is directly proportional to target range, R, is given by

$$t = \frac{2R}{c} \tag{1}$$

Since the beam deflection voltage of the display must be directly proportional to range, it is given by

$$V = kR = \frac{kct}{2} \tag{2}$$

where k is the constant of proportionality needed to give the desired scale factor.

Bistatic radar geometry is more complicated as shown in figure 1. Using the law of cosines it is easily shown that the difference between the propagation time from transmitter to target to receiver and the direct propagation time from transmitter to receiver is given by

$$t = \frac{R_t - D + \sqrt{R_t^2 + D^2 + 2R_tD\cos\phi}}{c} \tag{3}$$

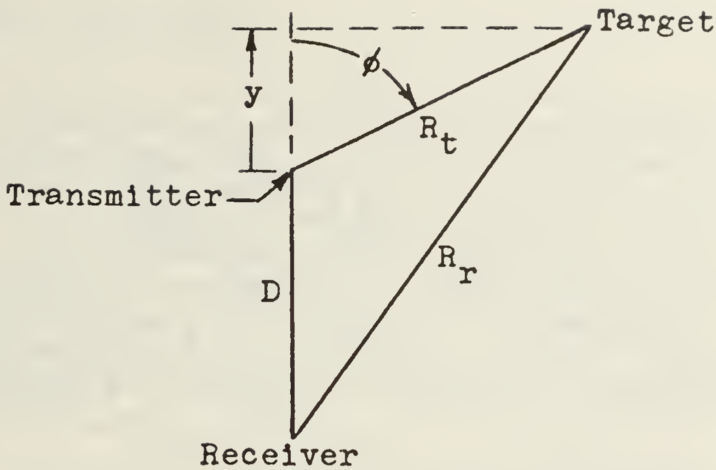


Figure 1. Bistatic radar geometry.

The display is centered about the transmitter. We want the deflection to be proportional to the distance from transmitter to target, or $V = kR_t$. Solving (3) for R_t we have

$$V = \frac{kct}{2}\left[1 + \frac{D(1 - \cos \phi)}{ct + D(1 + \cos \phi)}\right] \tag{4}$$

Figure 2 is a plot of the required deflection voltage vs time for various values of the antenna azimuth angle, ϕ.

If a linear sweep voltage were to be used as in equation (2) rather than the corrected voltage of equation (4), considerable distortion of the display would result. Figure 3a shows range rings and azimuth strobes as they would appear on a monostatic display. Figure 3b shows the same picture as it would be seen on an uncorrected bistatic display. Note the extreme distortion in the region between the transmitter and receiver, the two locations merging together at the center of the display. If the corrected sweep voltage of equation (4) is used for the bistatic display, the display appears as in figure 3b except that range resolution deteriorates, particularly in the region between transmitter and receiver. Since range resolution is inversely proportional to the rate of change of sweep voltage with time, reference to figure 2 shows that all range resolution is lost on the line directly between transmitter and receiver, but that little range resolution is lost in any direction when the transmitter-to-target distance exceeds the distance between transmitter and receiver.

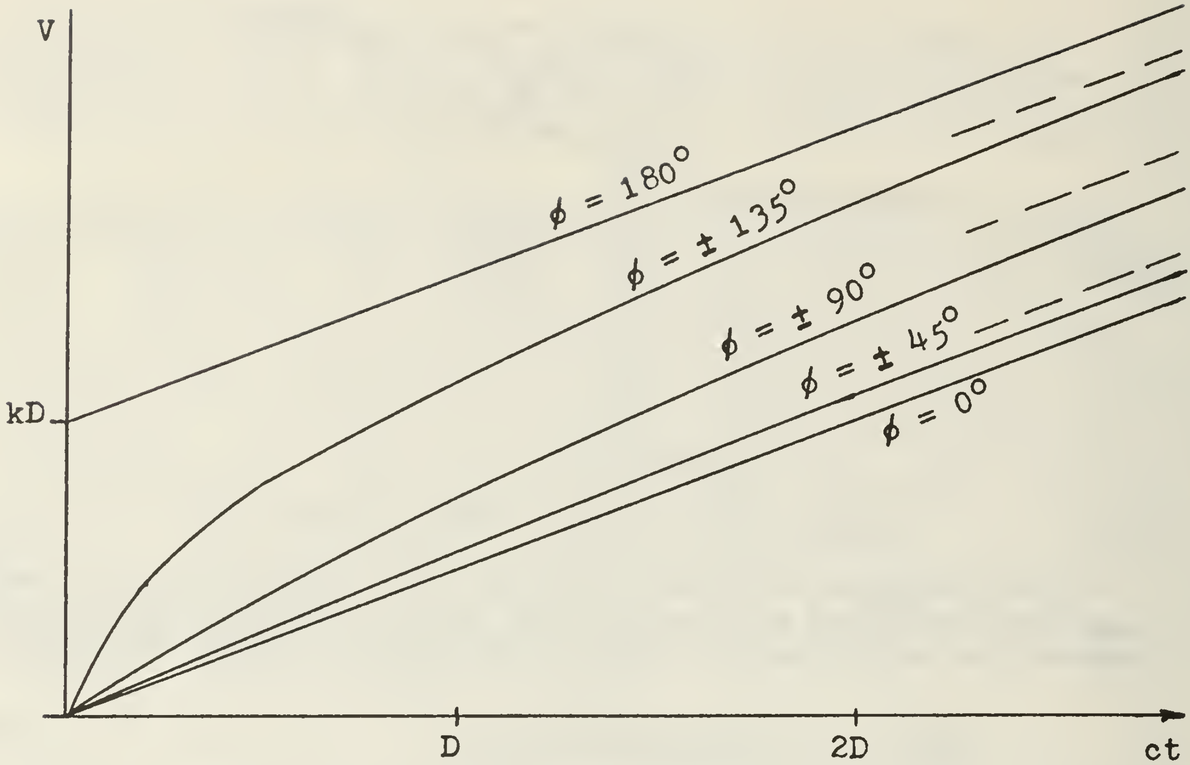
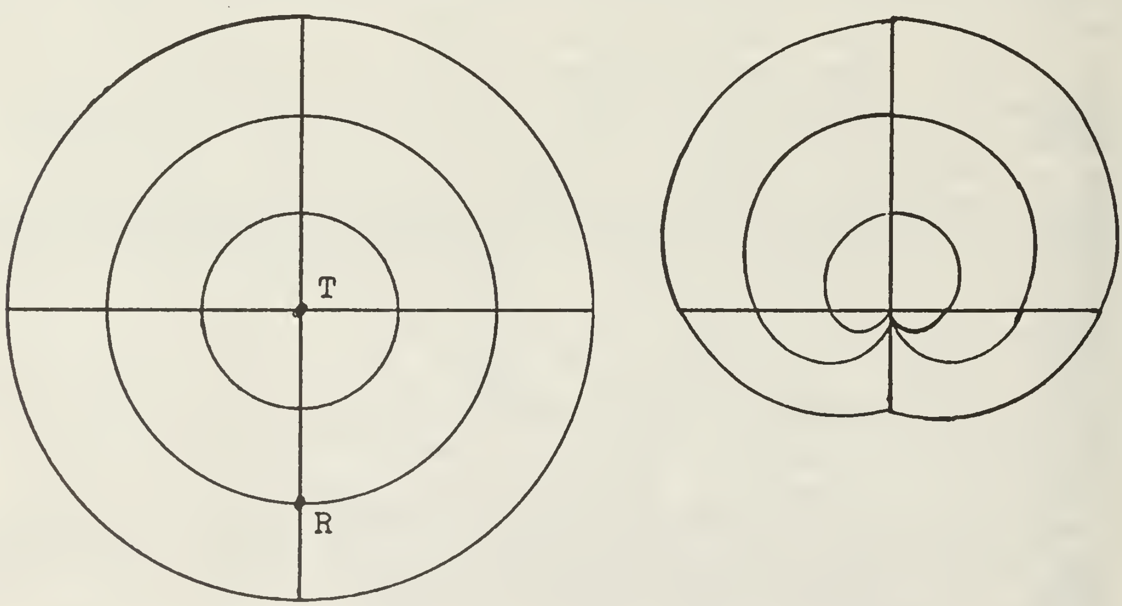


Figure 2. Sweep waveforms for various antenna azimuth angles. Asymptotes are shown by dashed lines.



(a) Monostatic display

(b) Uncorrected bistatic display

Figure 3. Monostatic and uncorrected bistatic displays.

THE RANGE SWEEP GENERATOR

In most bistatic radars built in the past, if the range sweep voltage was corrected at all the correction circuit was based on equation (4). Information on transmitter-to-receiver distance and transmitter antenna azimuth angle, ϕ, must be fed into the range sweep generator. The angle ϕ is easily determined with radars for which the antenna rotates at constant rate by measuring the time required for one revolution and noting the time when the antenna points directly toward the receiver. At this time $\phi = 180^\circ$. D is estimated, obtained through intelligence sources, or measured by passive means.

Commander Ralph. D. Hudson, USN, suggested a simplification of the range sweep generator circuitry, and this simplification was implemented in a bistatic radar processor built at the Naval Postgraduate School (1). If in equation (3) y/R_t is substituted for $\cos \phi$, and the resulting equation is solved for R_t, one obtains

$$R_t = \frac{ct}{2} + \frac{D(ct - 2y)}{2(ct + D)} \tag{5}$$

The equation for the sweep voltage can now be written

$$V = \frac{kct}{2} + \frac{kD(ct - 2y)}{2(ct + D)} \tag{6}$$

In the component resolver V is resolved into its two components, V_y and V_x, where

$$V_y = V \cos \phi, \qquad V_x = V \sin \phi \tag{7}$$

Now $V_y = ky$, so (6) can be rewritten

$$V = \frac{kct}{2} + \frac{D(kct - 2V_y)}{2(ct + D)} \tag{8}$$

Thus correction of the sweep waveform with changes in antenna azimuth angle ϕ can be accomplished by feeding the vertical component of the sweep voltage back into the sweep voltage generator. How this is accomplished is shown in block

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(1) Charles E. Carroll, "The Design and Fabrication of a Simplified Bistatic Radar Processor," Master of Science Thesis, Naval Postgraduate School, Monterey, California, December 1972

diagram form in figure 4. The first term of the sweep voltage waveform is generated in the linear ramp generator. The second term is generated in the sweep correction circuit, and is added to the first term to produce the corrected sweep voltage, V. The horizontal and vertical components of the corrected sweep voltage, V_x and V_y, are obtained in the component resolver, a sine-cosine potentiometer.

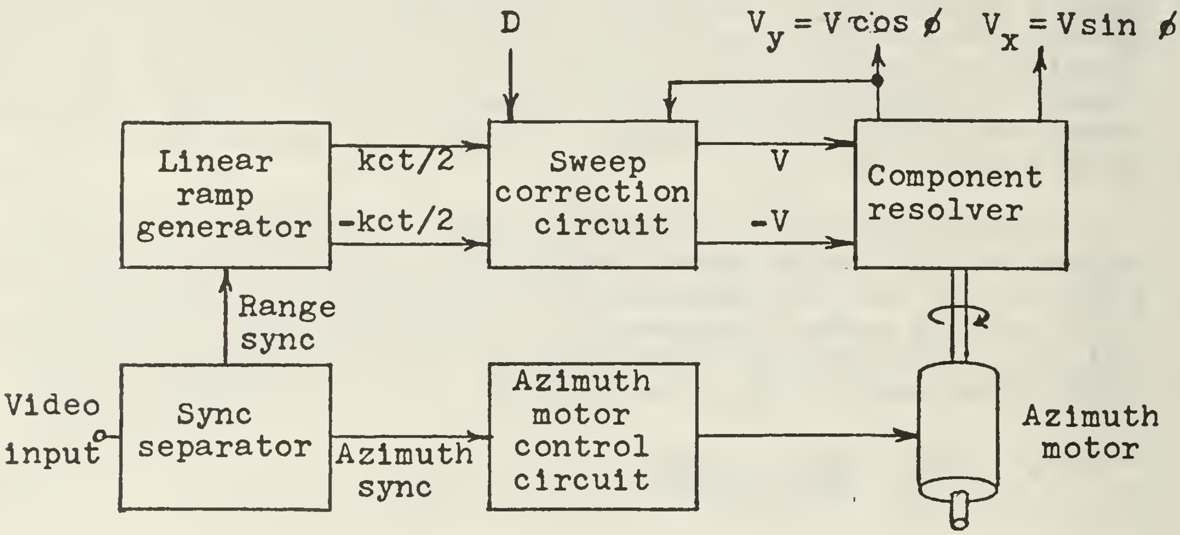

Figure 4. Range sweep generator block diagram.

The circuit diagram of the sweep correction circuit is given in figure 5. Proof that this circuit produces the correct waveform is given in Appendix I.

CONCLUSION

Although bistatic radars have a shorter detection range than do monostatic radars, and have poorer resolution in both range and azimuth, they do have important applications for the military services. To improve the accuracy of the information presented on a PPI display it is necessary to use a range correction circuit to produce the correct nonlinear waveform. An improved and simplified method of generating this nonlinear waveform has been presented.

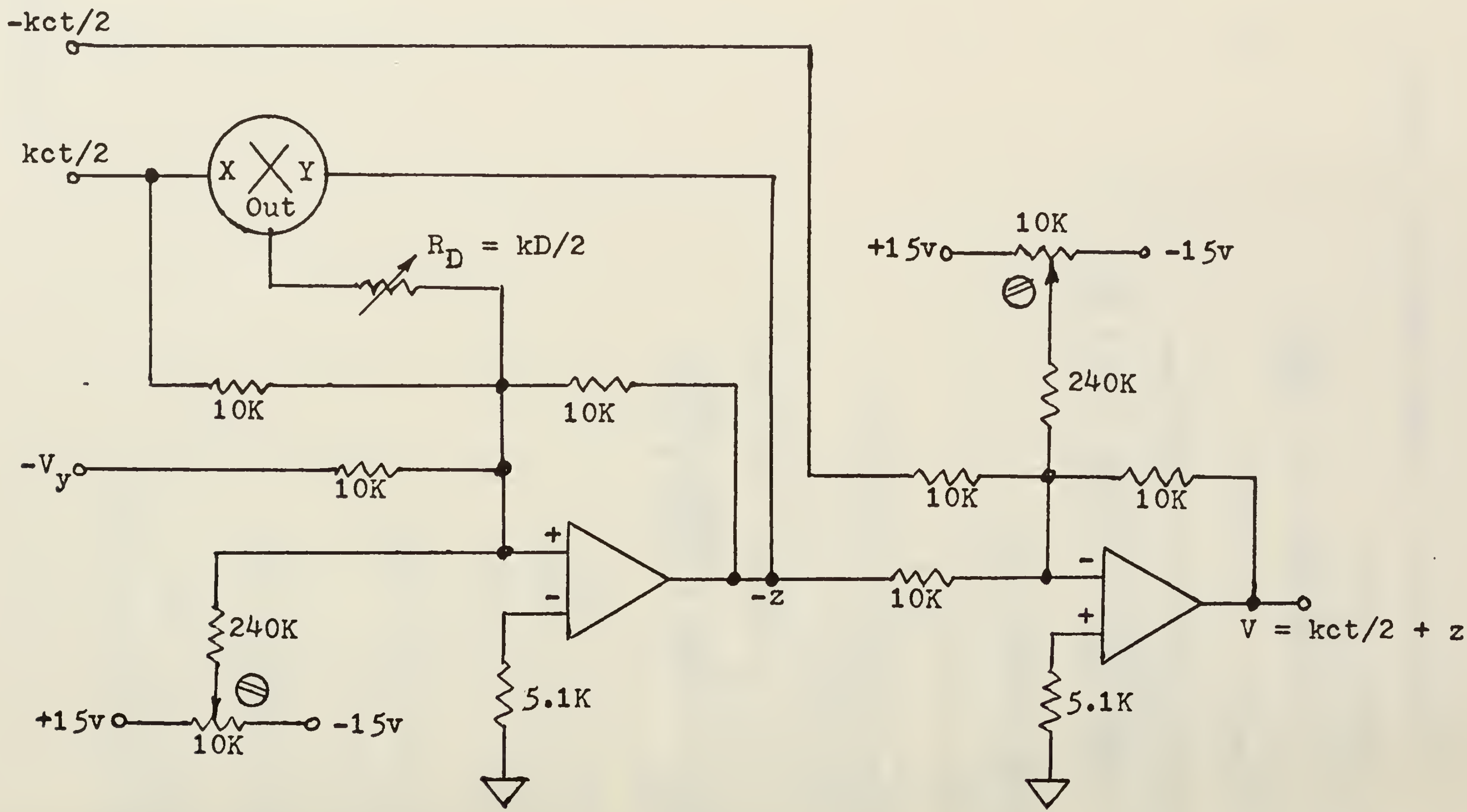

Figure 5. Sweep correction circuit.

APPENDIX I. VERIFICATION OF SWEEP CORRECTION CIRCUIT.

Multiplier output = XY/10

$$= \frac{1}{10}\,\frac{kct}{2}(-z) = -\frac{kctz}{20}$$

R_D = kD/2 kilohms

Output of first operational amplifier:

$$-z = -\,\frac{-kctz}{20}\,\frac{10}{kD/2} - \frac{kct}{2}\,\frac{10}{10} - (-V_y)\,\frac{10}{10}$$

$$z = -\,\frac{ctz}{D} + \frac{kct}{2} - V_y$$

$$z(1 + \frac{ct}{D}) = \frac{kct}{2} - V_y$$

$$z = \frac{D(kct - 2V_y)}{2(ct + D)}$$

Output of second operational amplifier:

$$V = \frac{kct}{2} + z = \frac{kct}{2} + \frac{D(kct - 2V_y)}{2(ct + D)}$$

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